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GRADUATE STUDY

Too much emphasis, these days, cannot be placed on the importance of graduate education and research. To the public, almost every chemist, physicist, biologist, and engineer is a venerable scientist, endowed with such knowledge that the synthesis of penicillin and the splitting of the atom are routine tasks. Why a cure for cancer, heart trouble, and other diseases has not been found is not correlated with this conception, nor is there any true appreciation of the difficulties involved in translating such electronic marvels as television from an experimental science to a commercial reality.

As Professor Calaway points out in his article in this issue, the general public must be made to "realize that science is not magic and that a vast amount of painstaking work is usually back of the 'discovery' that makes the headlines." Similarly, it must become increasingly clear to industrial leaders and educational institutions that such "discoveries" are becoming harder and harder to produce as science and technology grow increasingly complex; consequently, that more and more knowledge is required by those who engage in such work.

In the fields of science and engineering, there has long been more than a feeling that the baccalaureate is not sufficient to equip a man to engage in the practice of any and all phases of his chosen specialty. Professor Sweigert has gone into considerable detail on this subject in his article in the current issue, so that any lengthy discussion here would be redundant, especially in view of the additional remarks on graduate study contained in the article by Professor Calaway. Nevertheless, it is always important that the long-term, scientific value of graduate research be stressed in connection with any mention of its industrial significance, and as good an example as any is presented by the work outlined in the first article in this issue, on low temperature research.

This study of the behavior of materials at very low temperatures is a fundamental search for information, and the knowledge so gained will be added to the storehouse of science. When or if it is "used" is not of importance here; what *is* important is the fact that there will be few new major discoveries that are not based on fundamental knowledge, which can only be obtained through high-quality research.

In the case at hand, this project is serving two purposes: graduate students are contributing to the design and research phases as part of their work for degrees, thereby increasing their own knowledge and ability while at the same time aiding in the obtainment of basic scientific data. Only through the intensification of such graduate work can we be sure that science and technology in this country will continue to advance as they have in the past.

PROGRESS REPORT ON LOW TEMPERATURE RESEARCH AT GEORGIA TECH

By WALDEMAR T. ZIEGLER*

Research at very low temperatures is today of considerable practical as well as theoretical importance. Two previous articles in THE RESEARCH ENGINEER have described the superconductivity of metals, alloys, and compounds, one low temperature aspect which is currently of much importance, and the following article is devoted to an account of the progress to date in the establishment of the Georgia Tech Low Temperature Laboratory.

Since March, 1946, the writer has been engaged in setting up, at the Georgia Tech Engineering Experiment Station, a laboratory for carrying out research at very low temperatures. Great impetus was given to this effort in October, 1946, by a research grant[1] to the station from the Office of Naval Research, Navy Department, for carrying out research at very low temperatures upon the fundamental properties of the elements and their compounds, with the result that good progress has been made in the design and construction of the apparatus necessary for producing low temperatures and in the assembly of the not-inconsiderable amount of precision electrical equipment necessary for carrying out the contemplated research program.

RESEARCH AT LOW TEMPERATURES

The need for a better understanding of the properties of matter at low temperatures is a never-ending one. Additional experimental data are vitally needed on such physical properties as the tensile strength, brittleness, and thermal and electrical conductivity of metals and alloys, and on the thermodynamic properties of substances, to aid in the solution of many new technical problems. Of equal importance, there is also a great need for new experiments at very low temperatures that will increase our theoretical understanding of the fundamental properties of matter.

Two apparently closely related phenomena which, as yet, lack adequate theoretical explanation are the superconductivity of metals[2, 3, 4] and the superfluidity of liquid helium.[5] Both of these effects occur at temperatures below 20° K (−253° C). A satisfactory theoretical explanation of these phenomena may require drastic changes in the presently-accepted theoretical principles of the fundamental properties of matter.

Research at low temperatures is ofen divided somewhat arbitrarily into work at two temperature ranges. Temperatures down to about 50° K can be reached rather easily by using liquid air or nitrogen as a refrigerant. Temperatures below 50° K are usually obtained by employing liquid hydrogen (b.p.=20.4° K) or liquid helium (b.p.=4.2° K) as refrigerants, depending upon the temperature range to be studied. Liquid air or nitrogen can usually be purchased from commercial sources. Liquid hydrogen and helium are not available commercially and must be produced in the laboratory.

The production of liquid helium usually requires a supply of liquid hydrogen and therefore implies the availability of a hydrogen liquefier. The production of liquid hydrogen, in turn, requires a supply of liquid air or nitrogen as a refrigerant. Thus, the carrying out of experiments at liquid helium temperatures ordinarily requires that the low temperature laboratory be equipped with means for liquefying both hydrogen and helium and have available a ready source of liquid air or nitrogen.[6]

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[1] Office of Naval Research Contract No. N6-ori-192, Task Order I.

[2] W. T. Ziegler, "Some Properties of Matter at Low Temperatures. I. Superconductivity," *THE RESEARCH ENGINEER*, September, 1946, pp. 10-13.

[3] W. T. Ziegler, "Some Properties of Matter at Low Temperatures. II. Superconductivity of Alloys and Compounds," *Ibid.*, January, 1947, pp. 15-18.

[4] Many metals and other substances, when cooled to very low temperatures, show a sudden disappearance of their electrical resistance (i. e., infinite electrical conductivity) at some low temperatures characteristic of the materials in question, hence the term *superconductivity*.

[5] Liquid helium undergoes a remarkable change at 2.2° K. Below this temperature, it behaves as though its viscosity were exceedingly small, so that the liquid flows readily through extremely small openings.

[6] Mechanical refrigeration equipment for producing liquid helium, employing helium as the refrigerant gas and using liquid air as the only external refrig-

The properties of a considerable number of the rarer metallic elements, including most of the rare earth metals, have never been studied at all at low temperatures. The immediate objective of the Georgia Tech low temperature research, which is being performed under the sponsorship of the Office of Naval Research, is the investigation at liquid hydrogen and helium temperatures of the electrical and magnetic properties of certain of the rare earth elements and their compounds, with particular emphasis upon their possible superconductivity. This program will require the preparation of certain of these metals in a pure state and the conversion of some of these metals into the compounds that will be studied.

The long-range program envisioned at present includes the setting up of facilities for measuring the specific heats of these and other pure substances and equipment for studying chemical reactions at low temperatures.

THE LOW TEMPERATURE LABORATORY

During the past year, the construction of a new addition to the main building of the Engineering Experiment Station has been completed. This annex is a two-story brick structure, on the ground floor of which is located the Georgia Tech A-C Network Calculator Laboratory, described in the last issue of this journal.

The space occupied by the Low Temperature Laboratory is located on the upper floor of this building and consists of approximately 1,600 square feet, most of it being specifically designed for laboratory use. This floor is divided into a number of small rooms, each of which will house a particular activity. Thus, there are two rooms (16 x 16 feet) in which most of the actual low temperature experiments will be performed, a chemical laboratory (16 x 16 feet) for the preparation and purification of the materials which are to be studied, an instrument room (8 x 16 feet) in which most of the precision electrical measurements associated with the low temperature experiments will be made (provision has been made so that apparatus in any room can be electrically connected to the equipment in this instrument room), a small shop (8 x 16) feet for special repairs, and two research rooms (8 x 16 feet) where special experiments indirectly related to the low temperature experiments can be performed. Office and storage space is also provided.

The space in this new building became available on October 21, 1947. Actually, however, much of the equipment to be described later in this article was constructed prior to this date, in temporary quarters set aside for this purpose in the main building of the Engineering Experiment Station. Good progress has been made on setting up this equipment in the new building, though some months will be required before the facilities are sufficiently complete that the experiments planned at liquid helium temperatures can be undertaken.

LOW TEMPERATURE APPARATUS AND AUXILIARY EQUIPMENT

The principal pieces of equipment which will be required for carrying out the desired low temperature experiments are (1) a hydrogen liquefier for producing the necessary quantities of liquid hydrogen, (2) a helium liquefier, and (3) an apparatus, called a cryostat, in which the actual experiments are performed at low temperatures. In actuality, the helium liquefier and cryostat are being constructed as a unit. This unit will hereafter be referred to as the helium cryostat.

The hydrogen liquefier and the helium cryostat require numerous pieces of auxiliary equipment for their operation. Chief among these are (1) the high-pressure hydrogen gas purifier, (2) the high-pressure helium cycle, and (3) the electrical measuring systems.

At the present time, the hydrogen purifier and liquefier have been completed and the other units are nearing completion.

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erant, has been used with considerable success (see P. Kapitza, *Nature 133*, 708 (1934)). S. C. Collins *(Rev. Sci. Instruments 18*, 157 (1947)) has devised a cycle which dispenses with the need for an external refrigerant. These units are quite expensive, however.

RESEARCH—THE MASTER KEY TO PROGRESS

By **PAUL KENNETH CALAWAY***

Last year, the Georgia Tech Sigma Xi Club, as part of its program to foster research on the Georgia Tech campus, established an annual award of $300 for the best research paper published during the year by a member of the faculty. The 1947 award was made to Professor Paul Kenneth Calaway for his paper on "The Tolylmercaptopropanones and Their Condensation with Isatins." As an important accompaniment to the financial prize, the winner each year is privileged to address the faculty and friends of the school at a Sigma Xi public lecture which is a part of commencement week ceremonies, on a subject of his own choice. The following paper was presented on this occasion last year by Professor Calaway and presents an important message in a humorous, interesting manner.

When I was told that I was to have the honor of presenting this paper, my mind was filled with a maze of ideas as to a suitable subject. I read many speeches and essays by famous scientists and educators, and at last borrowed my title from a speech made by a witness before a Senate committee sometime after the close of the first World War. The senators were working on new tariff regulations to meet the changed conditions that follow every war, and the witness, an alert young man, was working on the senators. He recalled our sad plight when German dyes, drugs, reagent chemicals, laboratory glassware, and precision instruments were no longer available. He spoke of key industries and then told the startled gentlemen that scientific research was the master key to national progress in every phase of industry and national defense. "We must not be caught again," he declared, "with this master key to industrial progress and national defense in the hip pocket of pants that have gone to the pressers."

C. G. Fisher, president of the Fisher Scientific Company, was pleading for tariff protection to enable American research to become independent of imported reagents and instruments. Mr. Fisher was right a quarter of a century ago, and the giant strides of research and industry in this country since World War I are now history. Whether we like it or not, the world is changing at a dizzy pace. If these are times to try men's souls, then they are certainly times to try more experiments in the laboratory. We cannot survive in this age by the efforts of a handful of men working separately. We have many bathtubs, along with a host of new detergents, but it is not enough that an occasional Archimedes should leap from his tub and cry "Eureka!"

NEED FOR BETTER UNDERSTANDING OF SCIENCE

This is a time for team work, mutual understanding, and respect. There must be a fruitful relationship between industry and college and university faculties. President Bowman of Johns Hopkins had this to say in a recent annual report: "A sound working relation can never be established so long as a financially powerful industry regards a college or a university as a poor relation. A better society will come when all its parts are equally concerned about the kind of society we want and determined to encourage the processes that create it."

It is extremely important that the general public should realize that science is not magic and that a vast amount of painstaking work is usually back of the "discovery" that makes the headlines.

In the latter part of the 18th century, a certain Mr. Howard mixed together mercuric oxide, ethyl alcohol, and nitric acid, expecting to obtain mercury chloride, according to the prevalent theories of the day. Here is his amazing line of reasoning: the hydrogen of the alcohol was to combine with a part of the nitric acid to form hydrochloric acid, and this in turn was to be bound by the mercury. To the investi-

**Professor of Chemistry.*

gator's delight, he obtained a white crystalline salt, but then, more to his astonishment than delight, when he treated his crystals with concentrated sulfuric acid he obtained what might be called *ein heftiger knallender Verpuffung*. Mr. Howard had stumbled upon the preparation of mercury fulminate, now a much-used detonator, but many research workers juggled their test tubes and over 100 years passed before Wieland and his co-workers gave us the mechanism of the reaction.

The appearance of the first truly synthetic fiber, nylon, was headline news, but little or nothing was said in the daily press of the tremendous amount of research that had been done on the principles of condensation polymerization that lay behind it. After all, the early papers that were published in this field were classified as pure research on the fundamental principles of a complex reaction called polymerization. Such titles as "The Reversible Polymerization of Six-Membered Cyclic Esters" and words like "superpolyanhydrides" did not make sense except to a few chemists. Even the chemist who performed this basic research might have turned pale if he had known that he was helping to develop a synthetic fiber so precious that it was to be fought over by mobs of women at hosiery counters during the lean days of World War II.

Yes, everyone has heard of nylon, and it is unfortunate that so many people think of this polymer as a magic substance produced overnight from coal, water, salt, and air. I wonder how many times the early workers, doing "pure" or "stockpile" research in the field of polymerization, were asked the old questions, "What good is it?" "Why are you wasting your time with this theoretical stuff?" Or—let us forgive them—"Why don't you work on something practical?"

We *must* develop a better relationship between the scientist and the reporter before the nonscientist can have a true conception of the vast amount of work and the many disappointments involved in bringing about minute advances in the field of science. However, may I venture the opinion that we in the sciences should shoulder our share of the blame for any misunderstandings that occur?

Tennyson understood the situation when he said that "Science moves, but slowly, slowly, creeping on from point to point." I think he understood, too, that creeping sometimes bruises the knees and elbows of those who creep.

RESEARCH IS NOT INEFFICIENT

Someone has said that research is slow, inefficient, and wasteful. It is true that research is slow, but we deny the statement that it is inefficient or wasteful. We all know the story of Salvarsan, the drug used in the fight against syphilis. We know that it is called "606" because it was the six-hundred-and-sixth compound made and tested by Ehrlich and his co-workers as an anti-syphilitic drug. Ehrlich would have been released by a baseball club because of his low batting average, but who among us would call his work wasteful or inefficient?

When Paul Gelmo published his doctor's dissertation in 1908, he described the synthesis of a new coal-tar derivative, para-aminobenzenesulfonamide. His publication made impossible any subsequent patents on this chemical, which we know today as sulfanilamide. For more than a quarter of a century, this all-important chemical was used only as an intermediate in the synthesis of dyes, and even these dyes were never too successful from a commercial standpoint until a pharmaceutical chemist came along and did some research. In 1935, a paper was published reporting a 100 per cent cure of streptococcus-infected mice through use of a dye of the sulfanilamide group. As this work was performed in Germany, it was inevitable that the French chemists had to do something to surpass it. They called the Germans a few choice French names and went to work. Soon a French chemist and an Italian bacteriologist, working together, proved that this red dye broke down in the tissues into simpler parts and that one of these parts, Paul Gelmo's sulfanilamide, was the real strep killer.

It is significant that men of science in three great fields played their parts in the early work performed on this new discovery. In a very short time, research teams of men of medicine, bacteriology, and chemistry were hard at work on the syn-

thesis and testing of enormous numbers of closely related compounds. Here again, the vast majority of the substituted sulfanilamides proved worthless, but, as many of us know from personal experience, a few compounds were synthesized that have proved far better in many respects than the parent compound. And someone has called research wasteful!

These researches have uncovered much information of value. For example, all of the compounds showing outstanding promise in chemotherapy contain substituent groups on the amido nitrogen of sulfanilamide. Though the size of the molecules varies, four out of five of the most active compounds have the same grouping of elements ($SO_2NH-\overset{|}{C}=N$) as a part of the structure. Nearly all of the sulfa drugs that are active (with the exception of prontosil) are bacteriostatic rather than bactericidal *in vitro*, and it is likely that these drugs are effective *in vivo* because they inhibit the growth and rapid reproduction of the bacteria, thus permitting the natural defensive mechanisms of the host to destroy the invaders.

Woods and Fildes have found that para-aminobenzoic acid inhibits the effect of sulfanilamide *in vitro*, and recent work has shown that this same para-aminobenzoic acid is a growth factor for several types of bacteria. Adding these facts together, one may conclude that a likely interpretaton for the inhibition of sulfa drugs by para-aminobenzoic acid is that the latter compound is essential for an enzyme system in bacterial growth and that the closely related sulfa drug, when present in large amounts, is accepted in place of its neighbor compound but cannot perform the same function of promoting bacterial proliferation. Here is yet another approach to chemotherapeutic research; namely, the synthesis of compounds closely related in structure to an essential metabolite of a pathogenic organism.

DISEASE AND THE SOUTH

Disease has been called the number one enemy of the South. It is true that bacteria multiply more rapidly and become more virulent in warm climates. Many pathogenic organisms depend upon insect hosts to act as carriers, and these insects are here, ready, willing, and able to do their deadly work. Poor economic conditions in many sections are an aggravating factor, and, when we take stock, we find that the southern states have the highest disease rating of the nation. Disease costs us dearly, and the whole society must pay.

It would be impossible to estimate the value, even in dollars and cents, of a perfect cure for the common cold. In addition, let us not ignore arthritis, hay fever, malaria, tuberculosis, and cancer. The answers to all or most of these problems can be found if the nation can be aroused to the possibilities of research.

The four species of malarial parasites that affect man are of tremendous economic significance. Malaria is the most prevalent disease in the whole world, a situation which exists primarily because no known drug will prevent or completely cure this disease. Many hundreds of substituted quinolines and acridines were prepared by research teams during the recent war, and the most promising of these compounds were submitted to the National Research Council for more extensive investigation. As yet, malaria is still unbeaten, but the wealth of information collected during the war years has opened new leads to the problem, leads which will prove of real value to research men in the future.

NEED FOR TEAMWORK

The age of rugged individualism is almost over as regards the development of new compounds which add to life expectancy. More and more, scientific developments in all fields are brought about by *groups* of research men. In the main, it is coordinated effort that pays off today.

Once in a great while a lone worker has come up with a sensational discovery, but today this is the exception rather than the rule. Charles Hall is famous for his experiments in a woodshed in 1886, work that led to the invention of the electrolytic process for the production of aluminum. Hall was working alone in his woodshed, but there are men living today who insist that the research in child psychology that was being carried on in many woodsheds by research teams of irate fathers of that

day had more widespread results than the discovery of Hall. What a pity that these researchers did not keep accurate notes of their experiments for us to read in these days of juvenile and parental delinquency.

BIOCHEMISTRY OF THE INDIVIDUAL

In connection with this problem, and many others of human behavior, we might well heed the advice of Dr. R. J. Williams, who feels that it is certainly time to consider the interrelation of biochemistry and individuality. In the past, the fields of biochemistry and physiology have been concerned with the behavior of individuals solely because such behavior might throw light upon *how* the human body works. In short, we have sought the characteristics of the *hypothetical average man*—and, unfortunately, there is no such creature. Would it not be wisdom, then, to study the individual *as an individual* and to try to find out just *why* George P. Burdell* is such a ubiquitous person while Great-grandfather Burdell voluntarily secluded himself from society and lived a long and solitary life devoted almost entirely to philosophic meditation?

The answer to this question, in a broad sense, is that Great-grandpa Burdell had a pattern of metabolic machinery different and distinctive in some respects from that of anyone else—even Great-grandson George P. For example, a small dose of morphine modified the actions of specific enzymes in the old gentleman's body in such a manner as to produce a deep sleep, while the same dosage of the same drug reacts differently on the enzymes of George and only serves to create in him a feeling of great excitement. Great-grandfather Burdell was forced to give up one of his favorite beverages because the caffeine in the drink kept him awake at night, while young George consumes liters of the drink and still goes to sleep with his chemistry book in his hand the night before the big quiz. Burdell the elder always kept a 1.0 per cent solution of mercuric chloride in a quart Mason jar to apply to his cuts and bruises in the form of a wet bandage; George P. is unable to use this old-fashioned remedy because he has found his skin to be extremely sensitive to this salt even in solutions as dilute as 0.01 per cent. Old George started drinking the distillate from a neighbor's fractionating column at the age of 18, and continued this practice every day with no ill effects until he was accidentally drowned while on a fishing trip with some of the boys, at the age of 93. Young George is the sad victim of what is called "pathological intoxication" and always starts out to paint the town after only a few cubic centimeters of ethanol. Hours later, he awakens in strange and dreary surroundings, and soon Dean Griffin's sleep is disturbed by another phone call for help.

Let us repeat that these differences in human behavior are directly concerned with fundamental differences in metabolism and that these factors profoundly affect our emotions, our activities, our thinking.

According to Thurstone, each of us has a characteristic pattern of "primary mental abilities." These we possess in varying degrees, and somewhat independently of each other. To sum up, all of us are somewhat "spotty" as far as our mental abilities are concerned, but we try to keep the weak spots well covered. And biochemistry—our own little biochemistry laboratory—is probably responsible for our strong and weak "primary mental abilities." For example, the man who lacks the enzyme necessary to oxidize phenyl pyruvic acid in his body is, in some respects, feeble-minded, while the lack of enzyme-building niacin may result in a type of insanity. Don't look now, but someday the biochemists may come up with a wonderful chemical concoction that will improve man's intelligence. Recent work has indicated that proper doses of glutamic acid may have a beneficial effect on nerve activity in the brain. This amino acid has been tested for one year on a group of 69 children with results which indicate that their mental growth was twice as fast as that of normal children.

Since intelligence is a mosaic of separate abilities, it is hardly fair, and certainly unscientific, to classify individuals as average, smart, and brilliant. It would be unwise to say that a top-flight historian is "smarter" than a top-flight bacteriolo-

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**George P. Burdell is a hypothetical and perennial Georgia Tech student, long known to all Tech men.*

WHAT IS STATISTICAL QUALITY CONTROL?

By RALPH A. HEFNER*

Most articles on statistical quality control are written to instruct the potential user in the techniques and mathematics of the subject. The following discussion, however, deliberately departs from this approach and devotes itself to a simple, highly informative description of the basic principles, the reasons for their use, and the advantages thereof.

Many industries, both large and small, are already thoroughly acquainted with statistical quality control. Having used it in their plants for several years, they have verified for themselves the startling results that can be obtained by applying statistical principles to the control of the quality of their products.

Other industries, however, have heard only vaguely that a new technique has been developed for the control of product quality. These are the industries that are now asking the question, "What is statistical quality control"?

When a person asks this question, he is, in most instances, asking to be told what statistics has to do with the control of quality. It does not occur to him that his ideas of "quality control" may also need clarification, yet it often happens that the use of statistics in the control of quality is difficult to understand simply because no clear agreement has been reached as to what is meant by "quality control" itself.

One cannot thoroughly understand statistical quality control until an agreement is reached as to what is meant by "quality," then, what is meant by the "control of quality."

WHAT IS QUALITY?

What does the word "quality" mean when applied to a manufactured article? It requires only a moment's reflection to realize that when one speaks of quality, one may be speaking of a great many different attributes. A characteristic that would be regarded as of vital importance in one manufactured article may be a trivial characteristic in another.

In the manufacture of a crank shaft for in internal combustion engine, certainly, the diameter of the shaft is of vital importance. On the other hand, in the manufacture of an aspirin tablet, the exact diameter of the tablet is immaterial, but the weight of the tablet is of prime importance.

So it is with every manufactured article. There are always one or more characteristics that are of vital importance if the article is to be judged of good quality. This important characteristic—whether it be the length of a valve stem, the diameter of a bolt, the weight of a powder charge, the tensile strength of cotton yarn, the life span of a tire, the crushing strength of concrete, or any other desirable quality—is what a manufacturer tries to build into his product.

SPECIFICATIONS

Before production begins, the desired quality characteristics should be decided upon and then should be written into the specifications. The description of the article to be manufactured is in actuality the description of the *ideal* article desired, and it is the manufacturer's task to make his products as nearly identical to the ideal article as is practical and profitable.

Actually, of course, no manufactured article is *exactly* like the ideal article specified. One may wish to make a bolt 20 mm. in diameter, but, no matter how much care goes into its manufacture, the actual diameter is never *exactly* 20 mm. In fact, in spite of all that one can do, no two manufactured bolts selected at random ever have exactly the same diameter.

Here is a fundamental truth that must constantly be kept in mind. No matter what the desired characteristic of the article which one is trying to manufacture, it is inevitable that this characteristic will vary from article to article. There is always a certain amount of variation present, be it

*Dean of General Studies.

little or great. The fact that no two articles can ever be made exactly alike is inescapable, and one is forced to be content to make them as nearly alike as possible.

VARIATION

Obtaining manufactured articles of good quality, then, simply means that variation in the quality characteristic desired is being held within certain acceptable limits.

With this idea of quality thoroughly in mind, it is not difficult to agree on what "control of quality" should mean—that the amount of variation in the desired characteristic is to be held within as narrow limits as is practical or economical.

The fundamental ideas expressed thus far are so important that they can profitably be restated briefly. Inherent in every manufacturing process is a certain amount of variation. The amount of this variation depends upon the process itself, and it is the control of this variation that determines the quality of the finished product.

Two kinds or types of variation are found in manufacturing processes: *random variation* and the *variation due to assignable causes.*

To the statistician, random variation means that the process is operating under *a constant system of chance causes.* Stated more simply, random variation may be thought of as that amount of variation which can be regarded as usual or normal for a process when that process is doing the best that it can. Stated a third way—one perhaps more meaningful to the manufacturer—random variation is caused by so many and varied factors that it would be futile or uneconomical to attempt to find them.

Variability due to assignable causes means exactly what it says. There is present a cause of variation that can be sought for profitably and, when found, can be economically removed. Obviously, this latter type of variation can be controlled, and, just as obviously, the former cannot. Therefore in any instance the question always arises: "Does the process as it is now operating contain both types of variation"?

USE OF STATISTICS

It is precisely at this point that the science of statistics enters the picture. It is the tool that differentiates between the two types of variation, and it tells one when the cause of variation can be found and eliminated and when to let the process alone because it is doing the best that it can.

Statistical control of variation, therefore, deals with a quantitative measure of variability. It tells when the variation is large enough for a profitable search to remove the cause, or when it is small enough to let it alone. Statistical quality control gives one an objective rather than a subjective judgment of the variation that can be regarded as usual for any given process.

It is this fact that gives statistical quality control much of its power and usefulness. By its aid, an inexperienced foreman can judge a manufacturing process as well as the foreman with years of past experience to call upon. In fact, it frequently happens that the use of statistical quality control surprises the older foreman by showing him that his past experiences are not always an infallible guide. One instance of this might be of interest.

During the war, an old, established firm converted its plant to the manufacture of many of the various parts that go into an airplane engine. The chief engineer was responsible for the control of quality in this plant, and, hearing of statistical quality control, he availed himself of the first opportunity to take a course in which the subject was taught.

Returning to his plant, he thought of several processes that he knew were not operating at their best and hoped that his new knowledge would help him to locate and eliminate the troubles. However, his training in statistical quality control had been very intensive, and he did not feel that he knew enough about it to apply it to a process in which he knew there was trouble. As a start, and in order to gain experience with statistical quality control, he decided to apply its principles to a process that had never given him any trouble. It was true that the process was turning out some unacceptable pieces, but the scrap amounted to only five per cent of total production, and he knew that the output of all other firms manufacturing

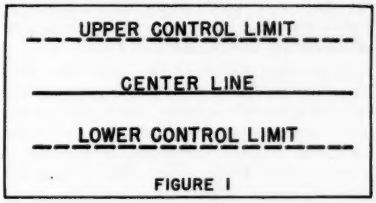

FIGURE 1

this same item was running as high as eight and ten per cent scrap. In addition, his previous experiences in making such items told him that it was unusually good to have only five per cent of the items fall outside the close tolerances allowed. In short, experience told him his process was doing the best it could and that it needed no further attention.

Applying the analysis of statistical quality control to this process, he was amazed to find that in actuality the process was not doing the best that it could. Upon investigation, he found that the parts in question were being made on four automatic machines and that an endless belt brought the finished articles to an inspection table where each was examined and the five per cent not conforming to specifications were discarded. By inspecting the output of each of the machines separately, he found that all the bad pieces were being turned out on one machine. This machine was immediately taken out of production and dismantled. A defective part was found, and, when it was replaced, the machine no longer produced articles that did not meet the specifications.

The above illustration is typical. As long as the judgment of a given process is subjective rather than objective, there is always the danger of deciding that the observed variation in quality is random, when in reality it contains variation due to assignable causes.

CONTROL CHARTS

To determine objectively the type of variation that is occurring in any given manufacturing process is relatively simple. This is done by constructing what is known as a "Shewhart control chart." To construct such a chart, one carefully examines a number of products of the manufacturing process under observation. A few simple statistical calculations are then made, and the chart is drawn, usually taking the form shown in Figure 1.

The solid line down the center is known as the *Center Line* and represents the average quality of the characteristic being manufactured. The dotted lines appearing on either side of the central line are called *Control Limits* and represent the extreme limits to be expected in the manufactured characteristic if the process is doing the best it is capable of doing. After the lines are drawn on the chart, the actual results of the manufacturing process are plotted as points. Each point usually represents the average quality observed in five selected samples.

If all of the points representing actual production fall within the dotted line, as shown in Figure 2, the process is said to be under *statistical control*. This means that the variation in quality is completely random, or that the process is operating under a constant system of chance causes. No amount of minor adjustment or tinkering with the process will affect the quality of the product; in short, the process is operating at its best.

If, however, some points fall outside of the control limits, as is the case in Figure 3, the process is said to be out of statistical control and is not turning out products of as good a quality as it is capable of manufacturing, meaning that there are one or more assignable causes of variation present. To one familiar with the manu-

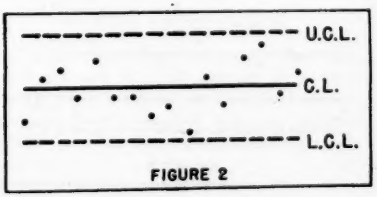

FIGURE 2

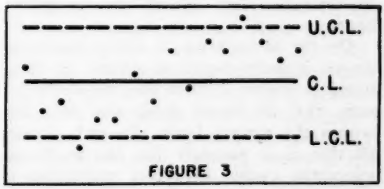

FIGURE 3

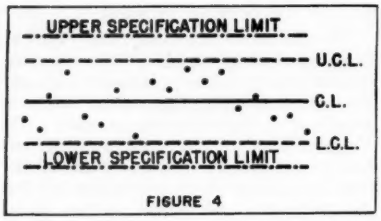

FIGURE 4

facturing process, it is usually a relatively simple matter to search for and to find these assignable causes of variation. Once the cause of variation is discovered, it can then be eliminated, with resultant improvement of the product. If all such assignable causes of variation are removed, then all the points representing future production will fall within the dotted control lines.

It is well to point out here that the control limits—the dotted lines that differeniate a process that is doing the best it can from a process that is not—are not placed on the chart arbitrarily, nor are they the results of some individual's opinion. These dotted lines are determined by the process itself. It is as if one went to the manufacturing process and asked it, "What kind of work are you capable of doing"?

"The dotted lines," would be the answer. The process in effect says, "This is what I am capable of doing. When I am operating at my best, all my production will fall between these two dotted lines."

As long as a manufacturing process is out of statistical control, there is no way of predicting what the quality of any future production will be. There is only one way to assure quality from such a process; it is necessary to inspect each and every article manufactured in order to discover and to discard those whose quality characteristics fall outside the acceptable limits.

On the other hand, if a manufacturing process is under statistical control, as illustrated in Figure 2, then one can safely assume that all future production will fall within the control limits. In such a case, all that it is necessary for one to do to assure the quality of future production is to take a sample from the process at convenient intervals to see that the process is remaining in control.

It is this statistical fact that has been of so much value to manufacturers using statistical quality control. Once their manufacturing process has been brought under statistical control, inspection is reduced to a very small fraction of what it was before statistical control was established. In many instances, this has resulted in a tremendous saving, since the manufacturer's cost of inspection has been greatly reduced while at the same time the quality of his finished product has been assured.

SPECIFICATION LIMITS

After a manufacturing process has been brought under statistical control, two other lines representing the *specification limits* can profitably be placed on the control chart. If it should happen that the specification limits fall outside the control limits, as illustrated in Figure 4, the manufacturer can rest assured that all of his production will meet specifications, and he may stop all inspection except for an occasional check to see that the process is remaining in statistical control.

Should the specification limits fall within the control limits, as illustrated in Figure 5, this presents altogether another problem. First, one must remember that the process is under statistical control, so that, even though it is doing the best that it can, there will inevitably be points falling outside the specification limits, since points may fall anywhere within the control limits for a process that is in statistical control. In such a case, a point outside specification limits, although it is within

Continued on Page 24

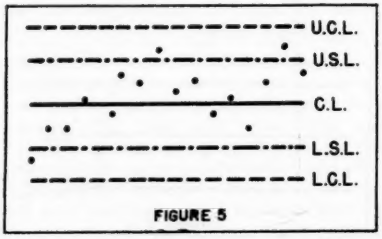

FIGURE 5

THE INDUSTRIAL SIGNIFICANCE OF GRADUATE EDUCATION AND RESEARCH IN SCIENCE AND ENGINEERING

By R. L. SWEIGERT*

Georgia Tech, which long has granted master's degrees in various fields of engineering and science, has recently been authorized to grant doctorates in engineering, and one department is already offering a program leading to such degrees. To an institution of higher learning, graduate study is of the greatest value. The intellectual atmosphere created attracts learned men as teachers and researchers, and in turn, the general level of education is improved. In the ultimate, however, the importance of graduate education and research to industry is what is really significant, for graduates with advanced degrees are equipped to be of far greater service than those who have not received the training and development involved in graduate study. The following article explains some of the reasons why this is so.

It is not necessary to recount here the great sums that are now being spent for research as compared with similar prewar expenditures. Nor, perhaps, does the lack of educated and competent personnel for education, for government, and for industrial research need to be discussed and emphasized. Both of the above points have been quite adequately covered in various journals. The lack of such personnel is an aftermath of the recent war, during which little attention or consideration was given to the advanced education of scientists and engineers, the number so engaged being minutely small and largely limited to those physically incapacitated for military service. Our allies and enemies were not quite so short-sighted as we; they permitted scientific and technical education to continue.

If graduate education and research had no industrial significance, we would not now be concerned about our present shortage of qualified personnel, brought about by the above-mentioned short-sighted national education policy of the war years.

TYPES OF RESEARCH

As is becoming common knowledge, there are two types of research with which industry needs to be concerned—basic and applied. *Basic research* is that type of study which involves the basic fundamental sciences and is engaged in without reference to practical use. Such research serves to advance the horizon of our basic knowledge. *Applied research,* by definition, is interpreted to mean that involving not the discovery of basic fundamental concepts, necessarily, but rather the practical interpretation and use of these concepts in new situations. Some of the workers in fields of pure science might prefer to call this second type *development* rather than research. However, practice has narrowed the meaning of development to typify the study of such problems as those needing solution in connection with the development of some actual practical unit, such as a gas turbine. There are many problems in the twilight zone between engineering and science that depend upon what we might call the engineering sciences, such as heat transfer, fluid mechanics, mechanics, thermodynamics, and electronics. These sciences, in a sense, take basic concepts from pure science and translate them into forms that are usable by the engineer.

Estimates by Dr. M. H. Trytten of the National Research Council place the current shortage of science Ph.D.'s at 5,700, with the possibility that this deficit may reach 13,000 by 1950. Our whole advance in basic science seems likely to be impeded, therefore. If this progress is hampered for any length of time, industry, when it approaches the frontier of known funda-

*Acting Dean of the Graduate Division.

mental knowledge, will of necessity have to slow down and perhaps even mark time for a period while this frontier is again being advanced. Furthermore, if graduate study is not intensified, industry will not have available enough men qualified to use the fundamental knowledge already available. Therefore, for continuous industrial progress, graduate scientific education and research are vitally needed, both to provide the stream of capable scientific personnel that is required and to contribute to the advance of the frontier itself.

ENGINEERING

Years ago, engineering was looked upon as the practice of an art. It has been based to a great extent upon empiricism, upon cut-and-try methods, and upon practical experience. Why, then, is a graduate and research program in engineering of importance? Perhaps a glance at the history of engineering might give us an answer. Improvements in the practical arts have been going on since the dawn of civilization. In the early development stages, one can identify only slight vestiges of what we call science; certainly, science as we know it today did not exist.

Modern science can be said to have started about the year 1600. While the writings of the men engaged in the study of science in its early days indicate that they were motivated, at least to a certain extent, by practical considerations, nevertheless this new science and the practical arts were still distinctly separated.

During the 19th century, however, the practical arts, through application of accumulative knowledge, were developed to the point where those who paid particular attention to these arts began to be known as engineers. These engineers, in such developments as the steam engine, found it increasingly useful to use certain ideas originated by scientists. This practice has continued at an accelerated pace to the present time, so that the modern professional engineer now uses science to a very large extent in the practice of his profession.

Because of the complexity of modern developments, the work of the engineer has tended to become functionalized. Thus we have engineers in any given field who are concerned with such functions as research, development, highly technical design, production, installation, and operation. Particularly in research, development, and highly technical design, the engineer needs to be in a position to take advantage of whatever concepts scientists develop that might be useful in the solution of the problems that he encounters.

To keep abreast of scientific developments, and to make use of such developments wherever practical, the engineer must of necessity carry his own educational level to the same level as that of the scientist. In carrying forward his work, the engineer is finding it necessary to use basic scientific concepts more and more, thus breaking any line of demarcation between engineering and science. At times, the engineer finds himself working extensively in the field of pure science and, likewise, the scientist at times finds himself over in the field of engineering.

NEED FOR GRADUATE WORK

Because of the functional development in the practice of engineering and the consequent breaking down of the boundary between engineering and science, the engineer is finding it an advantage and a growing necessity to carry his educational program through the doctorate level. Industry needs engineers who can take the work of the scientist and translate it for effective use. The more science that is directly employed, the more scientific and advanced must become the education of the engineers who must effectively perform the research, development, and technical design functions.

While the emphasis of the modern graduate program is of necessity still on education, and while the research output of one single student may be comparatively small, nevertheless the total of all such work provides a definite contribution to scientific knowledge as well as to the research education of the individual.

The techniques of graduate study are in themselves of value to industry. Textbooks are only of incidental importance. Primary

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PROSECUTION OF PATENT APPLICATIONS

By EDWARD TAYLOR NEWTON*

During the past year or so, THE RESEARCH ENGINEER has been publishing a series of articles on patents, designed to inform the engineer and industrialist on phases of a subject with which they are becoming increasingly concerned. Previous articles have dealt with patent requirements, invention records, patent searching, and the preparation of patent applications. The following article takes up the subject of the prosecution of these applications through the Patent Office, a complex procedure whose understanding is of considerable importance to those who want to obtain maximum patent protection. This series will be concluded in the May RESEARCH ENGINEER, after which it will be reprinted in booklet form.

An application for Letters Patent of the United States may be delivered to the Patent Office by mail, by express, or by hand, but in whatever manner the application is received in the Patent Office, the date of its receipt is stamped on it at once, since this date is a matter of the utmost importance to the applicant because it establishes for him at least the date of "constructive reduction to practice" of his invention.

In the Application Division of the Patent Office, the application papers, with the exception of the drawing, are placed in a file jacket, and the drawing is sent to the Draftsman's Division for approval or criticism. The Application Division has prints made of the drawing and secures the prints in the file wrapper. The drawing and other papers are then assembled and forwarded to the proper examining division, of which there are 69 at the present time.

CLASSIFICATION

Patent applications are classified according to the various arts and are taken up for examination in the regular order of filing[1], those in the same class of invention being examined, as far as practicable, in the order in which they were filed complete. However, applications which have been put into condition for further action by the examiner are given precedence over new applications in the same class of invention, and the following cases have preference over all others at every period of their prosecution: applications for reissue patents, cases remanded by an appellate tribunal, and applications which appear to interfere with other allowable applications. Except for these, applications will not be advanced for examination unless upon order of the Commissioner of Patents, either to expedite the business of the Patent Office or upon a verified showing which in the opinion of the Commissioner will justify so advancing it.

EXAMINATION

In any examining division, the merits of the invention are the matter of major consideration, but, in reading the application over for the first time, the examiner will not overlook clerical details, and this examination as to matters of form will extend to every part of the application. By a careful reading of the application's specification, the examiner strives to gain a thorough understanding of the invention, in order to enable him to make an intelligent examination of its merits and novelty. Having obtained a thorough understanding of the subject matter disclosed and claimed in the application, the examiner then searches the prior art as disclosed in patents and other printed documents.

OFFICIAL ACTIONS

Whenever, after this examination, any claim of an application is rejected, the ap-

Registered Patent Attorney, Atlanta, Georgia; B. S. in E. E., Georgia School of Technology, 1926; LL.B., George Washington University, 1934; M.P.L. and S.J.D., National University, 1935.

[1] Rule 63, *Rules of Practice in the United States Patent Office.*

plicant or his attorney will be notified of this in writing. The examiner's letter, or "Official Action," is typed in duplicate, the original being placed in the file wrapper and the carbon copy being mailed to the applicant's attorney. When a claim is refused for any reason, it is "rejected." For example, a claim may be rejected as too broad, indefinite, or incomplete. However, the usual basis for rejection is disclosure of the subject in a prior patent and may be set forth as "obviously fully met," "fully met," or "clearly readable on the reference." If the claim involves immaterial variations, it may be rejected as substantially met by, lacking invention over, or finding its full equivalent in the reference. Any document used in the rejection of a claim is called a "reference."

DIVISION

A requirement for "division" between independent inventions claimed in a single application is in effect a rejection of the claims on the grounds of misjoinder of inventions. Two or more independent inventions cannot be claimed in one application, but up to three species of an invention may be claimed in an application if it also includes an allowable claim which is generic to all the claimed species. If the several inventions claimed are of such a nature that a single patent may not be issued to cover them, the examiner will require the applicant to limit the description, drawing, and claims to whichever invention he may elect and to file additional applications for the other inventions if he so desires.

AMENDMENTS

In amending an application in response to a rejection, the applicant must clearly point out all the patentable novelty which he thinks the case presents in view of the state of the art disclosed by the references cited or the objections made by the examiner, and he must also show how the amendment avoids such references or objections.[2] The applicant has a right to amend his application before or after the first rejection or action by the examiner. In amending, the applicant or his attorney requests insertions, erasures, or alterations, giving the page and the line or the claim number and the line; and, as the specification is never returned to the applicant under any circumstances, he should be certain to retain a line-for-line copy of the application, as filed, so as to be able to direct amendments thereto. New claims may be added by amendment, and the specification and claims already in the case may be reworded by amendment, but the applicant is not allowed to introduce into the application by amendment any matter not disclosed in the application as originally filed. Any new matter sought to be introduced by amendment will be required to be cancelled.

FURTHER PROSECUTION

After re-examination and reconsideration of an amended application, the examiner writes the applicant his conclusions in another "Official Action," and the prosecution of the application is thus continued, unless the applicant abandons the application, until all of the claims are allowed or finally rejected, or some of the claims are allowed and the remainder finally rejected.

A period of six months in allowed[3] for the response unless the applicant is notified that it is required in less time. If an applicant neglects to prosecute his application for six months (or such shorter time as may have been fixed by the Commissioner) after the date when the last official notice of any action by the Patent Office was mailed to him, the application will be held to be abandoned. Before an abandoned application can be revived as a pending application, it must be shown to the satisfaction of the Commissioner that the delay was unavoidable. The fee for a "Petition to Revive" is ten dollars.

APPEALS

In regard to formal matters on which the applicant and the examiner cannot agree, the applicant may petition the Commissioner[4], while in the case of a final rejection of claims, or final requirement for division,

[2] Rule 68, *Rules of Practice in the United States Patent Office.*

[3] *Revised Statutes,* Section 4894.

[4] Rule 142, *Rules of Practice in the United States Patent Office.*

he may appeal to the Board of Appeals[5], upon payment of a fee of 15 dollars. The Board of Appeals in its decision will affirm or reverse the decision of the examiner in whole or in part, and the case is thereafter remanded to the examiner for such action, subject to the applicant's right of appeal, as will carry into effect the board's decision. If the examiner was sustained either in whole or in part, the next action must be taken by the applicant.

From an adverse decision by the Board of Appeals, an applicant may appeal to the U. S. Court of Customs and Patent Appeals[6] or he may proceed by bill in equity in the District Court of the United States[7], from which further appeal lies to the United States Circuit Court of Appeals. Otherwise, the applicant may cancel the rejected claims and request that the application be passed to issue with the allowed claims, assuming that at least one was allowed.

INTERFERENCES

Before permitting an application to issue as a patent, the examiner will make a further search in regard to interference. An interference is a proceeding instituted for the purpose of determining the question of priority of invention between two or more parties claiming substantially the same patentable invention, and may be instituted as soon as it is determined that common patentable subject matter is claimed in a plurality of applications or in an application and a patent. The fact that one of the parties has already obtained a patent will not prevent an interference, for, although the Commissioner of Patents has no power to cancel a patent, he may grant another patent for the same invention to a person who proves to be the prior inventor. Wherever the claims of two or more applications differ in phraseology, but relate to substantially the same patentable subject matter, the examiner will suggest to the parties such claims as are necessary to cover the common invention in substantially the same language. The parties to whom the claims are suggested are required to make those claims within a specified time in order that an interference may be declared.

The primary examiner retains jurisdiction of the case until the declaration of interference is made. Upon the declaration of the interference, the Examiner of Interferences takes jurisdiction of the matter, which then becomes a contested case. The applicant has a definite part to play in this procedure, and his notebook records are of vital importance to provide a basis for the showing required in the "Preliminary Statement"[8] regarding the earliest dates on which he may rely to prove inventorship. Also, in taking testimony, the applicant will likely prove to be a key witness in answering questions propounded by his attorney to outline the story of the conception and development of the invention, and he will be subject to cross-examination by counsel for the opposing party.

The final hearing in an interference is before a Board of Interference Examiners whose decision awards priority of invention. From the decision of the Board of Interference Examiners an appeal may be taken to the Court of Customs and Patent Appeals[6], or relief may be had by bill in equity in the District Court of the United States[7].

ISSUANCE

If, after all or part of this examination procedure, it appears that the applicant is justly entitled to a patent under the law, a notice of allowance will be sent to him, or to his attorney, calling for the payment of the final government fee of 30 dollars, plus one dollar for each claim in excess of 20, within six months from the date of such notice of allowance. The application will be forfeited for failure to pay the final fee within the time prescribed, but the Commissioner of Patents may, in his discretion, receive the final fee if paid within one year after the six-month period for payment has passed. Each petition for the delayed payment of the final fee must be accompanied by the final fee, by the petition fee of ten dollars, and by a verified statement in support of the petition.

[5] Rule 133, *Rules of Practice in the United States Patent Office.*

[6] *Revised Statutes*, Section 4911.

[7] *Revised Statutes*, Section 4915.

[8] Rule 110, *Rules of Practice in the United States Patent Office.*

Every patent will issue within a period of three months from the date of the payment of the final fee and will contain a short title of the invention or discovery, indicative of its nature and object, and a grant to the patentee, his heirs and assigns, of the exclusive right to make, use, and sell the invention throughout the United States and the territories thereof for the term of 17 years. The original patent is delivered or mailed on the day of its issue date to the applicant's attorney of record. A patent cannot be extended except by Act of Congress.

* * *

This brief summary of Patent Office procedure in regard to patent applications serves as a reminder that the acquisition of a patent is no simple matter. The careful inventor must take every precaution to see that the steps involved in his inventive process have been properly recorded and authenticated, that a search has been made (preferably early in the invention period) to determine what phases of his invention are new and useful, that his patent application is so drawn as to cover adequately the patentable features of the invention (no more, and certainly no less), and that the prosecution of the application through the Patent Office has been handled in such a manner as to obtain an issued patent that is as strong as possible, without giving way unnecessarily to unwarranted rejection of claims, yet with prompt acceptance of rejections where the data cited render the claims untenable.

To the inventor, many of these details may seem cumbersome and "red tape." It cannot be denied that Patent Office procedure is complicated, but neither can it be denied that this procedure is so designed as to permit the issuance, in an impartial manner, of the maximum number of valid patents within the budget of the Patent Office; i.e., the number and abilities of its patent examiners. The United States patent system is by no means perfect, but it is designed to give the inventor his due in return for what the inventor eventually gives the public—the knowledge contained in the issued patent.

LOW TEMPERATURE RESEARCH

Continued from Page 4

The Hydrogen Gas Purifier and Liquefier

In brief, the production of liquid hydrogen in the Georgia Tech Low Temperature Laboratory is accomplished by using electrolytic hydrogen gas compressed to 2000 psi, available commercially in standard cylinders. This high-pressure gas, after passing through a purifier to remove all condensable impurities, is passed directly to the liquefier where it is partially cooled by means of liquid nitrogen, after which a portion of it is liquefied by Joule-Thomson expansion; the portion not liquefied is discarded. The liquid hydrogen is transferred, intermittently, directly into the helium cryostat through a jacketed vacuum tube. The use of commercial cylinders as a source of compressed gas has been found to be more economical than the conventional compressor-gasometer system when moderate quantities of liquid hydrogen are needed.[7]

The purifier which has been built is similar in design and construction to one described by DeSorbo, Milton, and Andrews,[8] which the writer helped to design.

Compressed electrolytic hydrogen as supplied in commerce is usually about 99.7 per cent pure, the chief impurities being oil, water vapor, nitrogen, and oxygen. The removal of these impurities is essential for trouble-free operation of small liquefiers which use commercial hydrogen from cylinders as a source of compressed gas. The purifier which has been built is designed to remove these impurities by passing the impure gas first over activated silica

[7] F. G. Keyes, H. T. Gerry, and J. F. G. Hicks, Jr., *J. Am. Chem. Soc. 59*, 1426 (1937).
[8] W. DeSorbo, R. M. Milton, and D. H. Andrews, *Chemical Reviews 39*, 403 (1946).

gel maintained at room temperature and then over activated charcoal, cooled to about 80° K by means of a bath of liquid nitrogen.

Reactivation of the silica gel and the charcoal is accomplished by pumping on the traps for several hours at a pressure of 10^{-1} to 10^{-2} mm Hg (absolute) while simultaneously heating them to 140-150° C.

In tests to date, approximately 1,200 cubic feet of hydrogen gas (measured at 25° C and one atmosphere pressure) have been passed through the purifier, after activation, without any noticeable plugging of the liquefier by solid impurities.

The general design and details of construction of this hydrogen liquefier are similar to the apparatus described by DeSorbo, Milton, and Andrews,[8] which the writer helped to design. The design of that liquefier, in turn, was based on an apparatus described by Ahlberg, Estermann, and Lundberg.[9]

The Georgia Tech liquefier differs in one important respect from that described by DeSorbo, *et al.*, in that provision is made within the liquefier for cooling the incoming high-pressure hydrogen gas to 65° K before it enters the main heat exchanger, instead of only to 77° K (the normal boiling point of liquid nitrogen), by passing it through a cooling coil immersed in liquid nitrogen boiling under reduced pressure. This has the effect of increasing the average theoretical liquefaction efficiency from about 17.5 per cent to a value of 26 per cent at operating pressures of 1,500-2,000 psi.

The liquefier is a compact, relatively portable unit, so designed that its principal parts are readily accessible for inspection and repair. It is so constructed that the liquid hydrogen may be transferred directly to the helium cryostat which has been built, or to any other apparatus which it is desired to fill. The assembled liquefier occupies a floor space of 14 x 23 inches and is 48 inches tall. Figure 1 is a photograph of the assembled liquefier (rear view).

Liquid hydrogen has been produced in this liquefier in a number of test runs, and

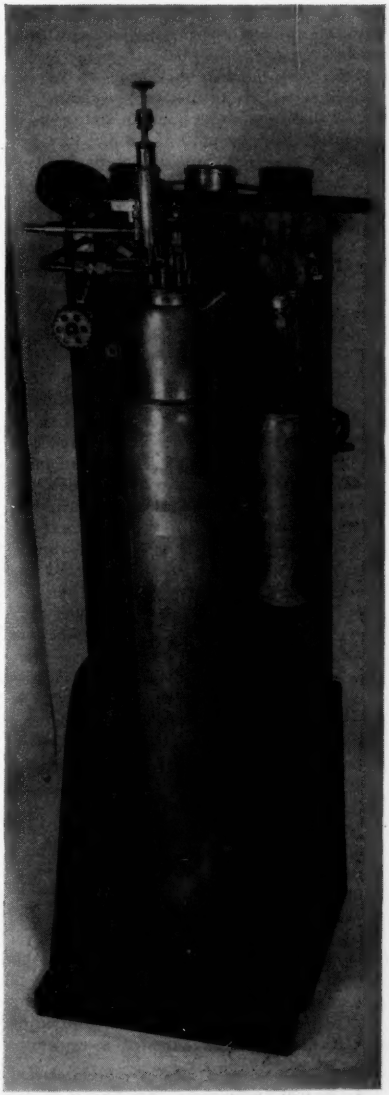

Figure 1. Rear view of the hydrogen liquefier, which is 48 inches tall and occupies a floor space of 14 x 23 inches.

[9] J. E. Ahlberg, I. Estermann, and W. O. Lundberg, *Rev. Sci. Instruments* 8, 422 (1937).

the liquefier has given trouble-free performance except when impure gas was used.

Once the liquefier has been cooled to the liquefaction temperature (about 70 minutes is required), liquid hydrogen is produced at a rate of 0.75 to 1.0 liter per hour with a flow rate of gas of 3 to 4 cubic feet per minute (measured at 25° C and one atmosphere pressure). After liquefaction has set in, approximately three liters of liquid nitrogen are required to produce one liter of liquid hydrogen. The rather rough measurements which have been made (so far at only one flow rate) indicate that, with a flow rate of three to four cubic feet per minute, the liquefaction efficiency is at least 50 per cent of the theoretical and may be considerably higher.

The Helium Cryostat

The helium cryostat which is being built (and which is now nearing completion) is modeled after one built by Dr. F. H. Horn and the writer.[10, 11] This cryostat utilizes design features well tested in the very low temperature field.[12]

The liquid helium is produced within the helium cryostat in two separate processes. The main charge of liquid helium is produced by suddenly releasing the pressure of high-pressure (say 2,500 psi) helium gas, previously cooled to about 12° K by the use of solid hydrogen, contained in a thick-walled copper vessel. This vessel is suspended in an evacuated space to decrease heat leak to it. The work done by the helium gas on expanding results in sufficient cooling that a considerable amount of liquid helium is obtained in the copper vessel. Under the conditions mentioned, a copper vessel having a volume of 100 cc will be about 70 per cent filled with liquid helium. Very pure helium gas is required, since even minute amounts of condensable impurities will result in the plugging of the small bore tubing employed.

The experimental chamber containing the samples to be investigated is suspended from the above-mentioned copper vessel. Liquid helium is condensed in the experimental chamber by passing helium gas at 15-30 psi through a tube wound around the copper vessel and connected at its lower end to the experimental chamber. This process results in the evaporation of an equivalent amount of liquid helium from the copper vessel. The advantages of this lower experimental chamber are twofold: (1) the experimental chamber, being suspended from the copper vessel whose temperature is 4.2° K (normal boiling point of helium), is thermally protected so that a lower temperature may be reached, for a given pumping capacity, than would be possible if the copper vessel were used as the experimental chamber, and (2) the samples may be placed inside the experimental chamber and hence in direct contact with the cooling medium, a procedure which is not feasible with the heavy-walled copper container.

The experimental chamber is so constructed that measurements of magnetic induction may be made on powdered samples and electrical resistance measurements can be made on materials obtainable in wire form.

The Helium Cycle

Liquid helium can be made by the method outlined above (the so-called Simon expansion method), using helium pressures available in commercial tanks (i.e., 2,000 psi). However, the percentage yield of liquid helium increases very considerably with increasing pressure. It is desirable, therefore, to have a helium compression system for raising the pressure of the purified helium gas to about 2,800-3,000 psi. Such a compression cycle, consisting of a compressor and a gasometer, can also be used for recompressing low-pressure helium gas not liquefied in the cryostat.

Considerable progress has been made in setting up such a helium compression cycle for compressing purified helium gas to 3,000 psi.

The Electrical Measuring Systems

The electrical measuring systems consist of (1) potentiometric means for measuring temperature, using thermocouples and

[10] F. H. Horn, *Dissertation*, Johns Hopkins University, Baltimore, Md., June, 1942.
[11] F. H. Horn and W. T. Ziegler, *J. Am. Chem. Soc. 69*, 2762 (1947).
[12] F. Simon, *Actes du VIIe Congres International du Froid*, Vol. II, 1937, p. 367.

resistance thermometers, and for the measurement of electrical resistance, and (2) a ballistic system for the measurement of magnetic induction. The precision electrical equipment includes a Leeds and Northrup 100,000 microvolt White double potentiometer.

FUTURE WORK

As is evident, the emphasis of the work so far performed has been concentrated on the design and construction of the requisite facilities and the planning of the experiments mentioned in this article. It is anticipated that actual experimentation with this equipment will be under way this spring.

ACKNOWLEDGEMENTS

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RESEARCH

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gist, but it would be reasonable to assume that these two men have contrasting patterns of mental abilities. We would be far happier with our fellow individuals if we understood these differences and were big enough to make allowances for them with the full understanding that each has his place in the sun.

To quote Dr. Williams, "As a defense against the evils of society, as a defense against the atomic bomb and biological warfare, we need to know ourselves better and to know our fellow human beings better . . . Understanding cannot be fully attained without the utilization of all the tools of science to study real individuals."

Has any other defense been advanced against the atomic bomb and its most horrible companion, biological warfare? Dr. Williams is a man of outstanding reputation, and he certainly deserves a hearing when he suggests a thorough study of the interrelations between individuality and bio-chemistry.

I have tried hard in this paper to abstain from mentioning the atom bomb. We have all heard so much about it that we often would more than like to forget it. We are uneasy and frightened, and, in our weak moments, we sometimes feel that if all the men who worked on the device were laid end to end, it would be a very good thing. Of course, this is an absurd attitude, and we realize it. There is no short-cut to peace: the bomb is here, and we must learn to live with it by redoubling our efforts to create a better world through research and education.

SOUTHERN POTENTIALITIES

We in the South can help by pulling hard on our own bootstraps. Better things for better living are all about us if we will only reach out to take them. The South possesses inexpensive power and raw materials. We supply 65 per cent of the nation's petroleum, 70 per cent of the natural gas, and 40 per cent of the coal. The South has phosphate, sulfur, bauxite, barite, galena, feldspar, Fuller's earth, iron ore, limestone, granite, and ceramic clays. We are most fortunately situated with respect to the production of organic raw materials. There are tung oil trees, southern slash pine, sweet potatoes for the production of starch, hemp and flax, and cotton. There is great promise in the ligno-cellulose plastic industry for converting waste wood products into materials of great value. There should be more utilization of so-called farm wastes,

such as straw and stalks. The production of cotton textiles is a fertile field for research into bleaching agents, detergents, wetting agents, synthetic dyes, starches, flame-proofing chemicals, water-repellent finishes, and mildew inhibitors.

For years, we in the South have been allowing at least part of our most valuable raw material to slip through our fingers—I am speaking of our bright young men who go north or west to graduate schools from which many do not return to us. At least we are consistent: it is an old story to allow southern raw materials to be processed in some other locality. What a cry we would make if these men were potential All American half-backs.

The South will never reach its deserved stature until our graduate schools are second to none. President Van Leer of Georgia Tech is well aware of the importance of graduate work, and I am taking the liberty of quoting from one of his recent annual reports: "It is impossible to have a great technological institute without a strong graduate division. Graduate work improves all teaching, graduate and undergraduate, by attracting a stronger faculty—few outstanding men will teach in a technological institution if there is no opportunity for graduate and research work. The graduate students themselves aid materially by serving as teaching and research assistants and, in some cases, by actual teaching." In the same report, Colonel Van Leer lists the three major objectives of graduate work: "(1) It enables the graduate student to secure advanced academic degrees which are frequently necessary in a specialized field, (2) it increases the specialized knowledge of the graduate student and makes him a master in a specialized field, and (3) it contributes to and actually advances the boundaries of human knowledge by specialized discoveries."

Other southern educators are aware of the importance of graduate schools, and it is time for everyone to perceive that more and better graduate work will mean increased prosperity. We must have public support, and we should call on "patient, educated money" to speed up the development of this all-important phase of education. Even one chemical discovery, backed by money, advertising, and selling, could change our entire economic setup. Just one important discovery could mean new homes, new factories, and a new outlook.

More industrial fellowships must come our way, and they *will* come if we are able to convince industry that ours is a paying proposition. After all, in our American way of life, a man is in business to make money. For example, I can hardly believe that a certain manufacturer bottles his product with the sole purpose of creating "men of distinction." It is true that most industries serve the public well, but their main purpose, individually, is to make a profit. This is as it should be, and the American businessman has done more than his share to make this nation the greatest in the world. However, there is more that he can do—and it is our task to sell him on the value and true meaning of research and education.

There is room, incidentally, for research on the art of teaching. We in the teaching profession sometimes feel that we are forgotten men—and there is much evidence to support this assumption—but I think that there is a bare possibility that we ought to devote some attention to putting our own house in order. A professor should be a man of courage, a researcher after new methods and new knowledge. Alfred North Whitehead has said that every single generalization respecting mathematical physics that he was taught at Trinity College has now been abandoned. But this youngster of 86, who has seen the sciences adopt and discard one "certainty" after another, is undismayed. He knows that the new theories that are advanced from time to time as "indubitable truths" are an integral part of the upward climb of every science. It is not enough that a university devote itself entirely to a study of existing knowledge "supported by orthodox literature, by orthodox expositions of theory, by orthodox speculations, and by orthodox experiments disclosing orthodox novelty."

Let us recognize research, then, in the broad sense—as that adventuring, searching spirit which gives new life to individuals, to industries, to schools, and to nations.

GRADUATE EDUCATION

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attention is given to the scholarly papers which in journals and monographs represent the vanguard of scientific and engineering knowledge—the records of current activities in laboratories, or studies that will shape tomorrow's engineering practices. The student becomes acquainted with a whole new literature of vital importance in his professional career; had he ceased his formal education at the baccalaureate level, it is doubtful if he could have read this material with understanding even if he had known of its existence.

The familiarity which the graduate student gains with the techniques of advanced research is of invaluable importance in his industrial career. As George Zeigler, Research Associate of the Midwest Research Institute at Kansas City, points out, "The experience and training of industrial research . . . can be gained by most people only through work at the graduate level. Men lacking graduate training usually experience difficulty in advancing beyond the research assistant stage."

This deficiency is not usually overcome by long experience. If experimental research is to be the student's objective, it is necessary that he master in school as many experimental techniques as possible, because there are so many new things to learn after he starts to "work" that there is little time available for practicing techniques.*

H. S. Rogers, president of the SPEE (1944), remarks that "perhaps the field of engineering education which will be influenced most by war experience is that beyond the undergraduate program in the graduate and postgraduate years. The expansion of research and the development of new techniques, particularly in chemical, electrical, and aeronautical engineering, have surpassed any experience in history. While much of the development has been in the fields of application rather than basic theory, the technology involved has been upon such a high level that graduate work is becoming increasingly more necessary and special in-service courses for engineers in industry more desirable. These developments will bring more formal course organization into the program at the master's level and will stimulate the expansion of work of a more fundamental nature at the doctoral level."

Industry's own opinion of the value of advanced degrees is best expressed quantitatively. In a recent survey of industrial demands for engineering graduates, the ASEE found that the estimated future annual demand for men holding advanced engineering degrees for work in research and development is expected to be 264 per cent greater than this same demand in 1938. Commenting on this, the ASEE committee says: "Not only are companies increasing the ratio of research engineers to total engineers, but in the research field they indicate a need for a higher percentage of engineers holding advanced degrees . . . This sharp increase in emphasis on research and development is a very significant factor in any determination of future needs for engineers in that it tallies with the demand for more engineers with advanced degrees and may well point to the increasing need for the extension of more basic science in undergraduate engineering curricula. Both of these points have been emphasized in recent years by engineering educators who have watched the trend away from 'handbook' engineering and toward the application of more fundamental science to modern engineering problems."

Industry is asking for more and more engineers who are sufficiently well grounded in the fundamentals of pure and applied science to enable them to work intelligently in those areas where formulas and handbooks fail, men who are at the same time aware of the social and economic implications of their profession. Graduate study, by providing an additional one to three years of professional training, makes it possible to place considerably less emphasis on specialization in the undergraduate curricula, thus permitting broader training in science, mathematics, and the humanities. Still more study in advanced mathematics and pure science are then provided in the graduate curricula, with emphasis on research, and specialization can be approached in a manner that does not destroy breadth for the sake of depth.

*The cover of this issue is illustrative of graduate student participation in Experiment Station research.

Graduate education and research, either directly or indirectly, provide men who have the background that industry needs today — and this by a selective process that gives advanced training only to those who have demonstrated that they have the best chances to profit from such education. Through such study, qualified personnel are provided and the frontiers of knowledge advanced.

QUALITY CONTROL

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control limits, represents characteristics of unacceptable quality. Therefore, although the process is under control, some scrap will inevitably be manufactured. As has been stated before, no amount of adjusting or tinkering with the process will improve the situation. Nothing short of a major change in the process, such as new machines, new methods, new materials, or different operators will bring the control limits closer to the central line. If the specification limits cannot be widened, either the process must be completely changed or the unacceptable quality items must be screened by 100 per cent inspection.

Manufacturers who have been using statistical control state that, in many such instances, a conference between the manufacturer and the user of the product has often resulted in a relaxing of the specification limits. When all parties concerned are familiar with the assurance in quality that is given by a process that is under statistical control, they usually find they do not need the protection of extremely tight specification limits.

WHO CAN APPLY THE METHOD?

Many manufacturers, hearing of statistical control, would like to try it but are frightened by the word "statistical." They fear the need of a highly trained statistician to do the job. Actually, such is not the case. In fact, it is much better to take a person already familiar with the manufacturing process and then teach him how to use statistical quality control. It has been aptly and accurately stated that statistical quality control is less than five per cent statistics and over 95 per cent engineering or technical knowledge of the process under consideration.

Any person with as much as high school training in algebra and arithmetic can make the calculations necessary to draw the control chart and place the production points on it. In most plants, relatively low-salaried clerks do this part of the work. Once the charts are prepared, they are studied by the chief inspector or production engineer, or whoever is in charge of quality control. If the person in charge has had sufficient training in the control of quality through statistical methods, he is then able to interpret the charts and to take whatever action they indicate to be necessary.

During the war years, statistical quality control was taught to chief inspectors and engineers from war plants in ten-day intensive courses. It was found by experience that a person familiar with a manufacturing process could be taught enough statistical quality control in ten 8-hour days to enable him to start using the process successfully in his own plant.

These ten-day wartime courses were taught under the auspices of the Office of Production Research and Development. Since the close of the war, several schools scattered throughout the United States have continued to offer ten-day intensive courses in statistical quality control, once or twice a year. The tuition charge, which includes all the necessary books and materials, is usually around $100. More and more manufacturing plants are learning that it is highly profitable to meet the cost of training their personnel in this new method of controlling quality. In most instances, the first application of statistical quality control results in a saving to the manufacturer that more than meets the entire cost of the course.

The use of statistical quality control, then, simply adds a few easily employed statistical tools to the store of knowledge already possessed by the men responsible for the control of quality of manufactured articles. These tools, however, enable a quality control department to bring to bear on its tasks the powerful theorems long used by the statistician.